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The Infrared Frequencies of DNA Bases: Science and Art by S. Alexjander

Abstract

In 1988 the author and biologist Dr. David Deamer collaborated on a science/art project which consisted of measuring the vibrational frequencies of the four DNA base molecules, translating them into 'sound,' programming them into a Yamaha synthesizer and using this tuning system as the basis for original compositions entitled *Sequencia* (1990 and '94 CD). The realization of biological, infrared frequencies into sound has resulted in unusual insights into the harmonic fabric of DNA, and reactions from listeners suggest that our bodies may have a way of recognizing their own electromagnetic patterns through the resonance of tone.



*See deep enough, and you see musically;
the heart of Nature being everywhere music,
if you can only reach it."*
—Thomas Carlyle

Introduction

If we could hear the body, delve into its rhythms and frequencies, what might it sound like? Would we recognize patterns pleasing to the ear... consider them beautiful...musical? Is our biology harmonically ordered in any way? And if so, so what? There are many ways to explore such questions, and one direct way is to access the frequencies of deoxyribonucleic acid (DNA), the primary carrier of genetic information for all living organisms.

In 1988 the author, a composer, posed these questions to Dr. David Deamer, a cell biologist (now at UC Santa Cruz). Dr. Deamer is internationally known for his research on the origins of life. Some years before he had created very interesting music cassettes (DNA Suite and DNA Music) based on the mapping of sequences of bases in the double helix of DNA. He was intrigued and offered to help.

One significant constraint with this project required that, rather than 'mapping,' or assigning arbitrary pitches to 'hear' patterns, the actual vibrational frequencies were to be collected directly from the molecular realm. These frequencies would then be arranged as 'scales' of tones, and used as the basis for musical composition. Two years later, on April, 1990, (Earthday) the cassette version of Sequencia was recorded, and in 1994 the CD with additional music was produced. Sequencia consists of three performances of original music – Eikos, Sequencia and Pataphysical Thymine – performed on traditional instruments plus electronic keyboard, based entirely on a tuning system derived from certain frequencies that occur naturally in DNA.

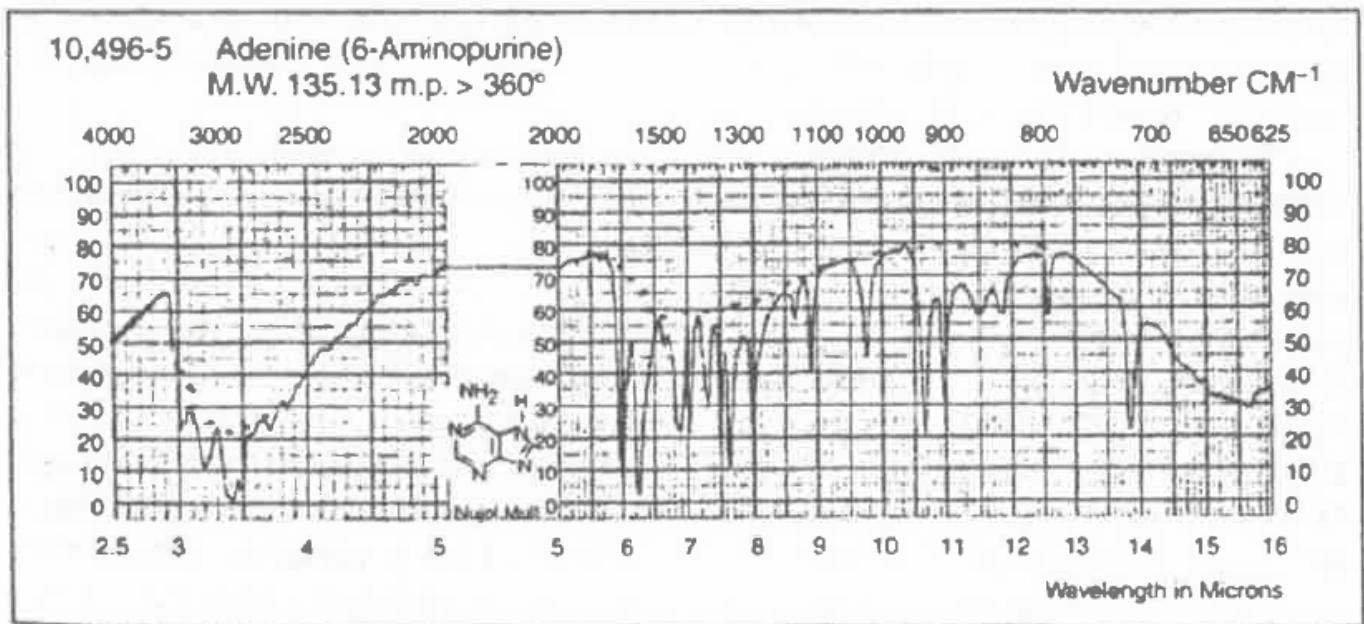
Methods and Materials: The Science

There are about three billion base pairs in the DNA of each human cell. If they were strung out they would measure about three feet long. Yet each of these bases remains absolutely consistent in its chemical makeup. The four DNA bases, adenine, cytosine, guanine and thymine, consist each of carbon, hydrogen, oxygen and nitrogen.

There exists a variety of chemical structures, including C=O, N-H, C-H, O-H, and C-O whose bonds bend, stretch, and rock upon absorbing infrared light with a specific frequency related to the energy and strength of the bond and the mass of the nucleus of the atom. A tighter, smaller bond from, say, hydrogen, will absorb light with a higher wavenumber (number of waves per centimeter), and a higher 'note' in the infrared spectrum. (The original energy for these motions comes from the sun in the form of infrared radiation. Solar photons cause heating in the molecule as orbiting electrons jump to a higher energy state). The tuning system for Sequencia was derived directly from the laboratory chemistry of the four bases, and had nothing to do with a particular gene, or configuration of bases along a helix.

The process of "collecting" frequencies from the bases of DNA begins with a spectrophotometer, a device about the size of a breadbox. In this instrument, infrared light with frequencies ranging from 600 to 3000 wavenumbers (in units of cm^{-1}) is passed through the sample, in this case a base molecule of DNA. The bases of DNA and RNA have certain resonance frequencies related to the absorption of infrared light. This is a common property of all organic molecules, and in fact infrared spectra are used as a primary diagnostic characteristic in analytical procedures.

As the light is passed through the sample, it is absorbed by the sample at specific frequencies and the instrument plots the absorption bands as a spectrum (Fig. 1), a process analogous to a glass chime sounding when it is struck. For example, the C-H (carbon-hydrogen) bond absorbs infrared light with a wavenumber of approximately 2900 cm^{-1} .



1. Spectrophotometer readout of wavenumbers for the DNA base adenine.

[Figure #1] (Spectrophotometer readouts of wavenumbers of the four DNA bases: adenine, guanine, thymine and cytosine).

Once the wavenumber is known, the following equation is used to convert it to hertz (Hz):

$$\text{Frequency (Hz)} = \text{velocity (speed of light)} \times \text{wavenumber}$$

If the wavenumber is

These gigantic hertz numbers are problematic in two ways. First, they are light frequencies, not sound. And second, they are too high to be heard, even if they were sound, since our ears can only register frequencies between 20 – 20,000 Hz. Below 20, vibrations are 'felt' rather than heard, and frequencies above 20,000 belong to ears more discerning than ours.

The problem of getting the frequencies within hearing range can be solved by recognizing that any hertz number divided in half or doubled will produce its corresponding lower or upper octave, respectively, whether it be sound or light. Thus, 8.7×10^{13} Hz can be divided in half, again and again, to create lower and lower octaves. Finally we derive, after dividing 36 times, a workable frequency which, if it were sound, would fall within the range of hearing. Thus we would have for the example above 1266, which is a very comfortable frequency for the ear, corresponding to a (slightly sharp) D#.

The question of 'translating' light into sound is more a philosophical one. Sound sped up can of course never be light, since the former depends upon molecules to push around while the second derives from electromagnetic radiation. One could argue that what is important here is not so much the medium but the ratios involved; the relationships between frequencies. The ears can detect about 10 octaves of sound, while the eyes can only perceive a little over one octave of light, or color. An octave in light is the same ratio as an octave in sound....2:1. A perfect fifth, or a relationship of 3:2 is the same proportion in light as in sound (and can be continued into the

world of geometry, architecture, movements of the planets and so forth; anywhere there is a periodic or regular vibration). By discovering patterns of ratios in light, we are simply translating into a sound medium to "hear" what information they might contain and how they relate to each other. It could also be argued that both light and sound refer back to a common archetype which, as yet, is unknown to us, not unlike cousins who relate back to a common relative.

Again, four base molecules were measured: adenine, cytosine, guanine and thymine. Each base molecule after being subjected to light yielded about 15 or 18 frequencies; 60 in all. Once this data was collected, it was iterized down into a hearing range and programmed into a Yamaha DX7 IID synthesizer which would create sound banks from any hertz numbers provided as input. A special electronic keyboard was needed because the tunings that were derived were almost all microtones, or tones smaller than a normal half-step (for instance any c to c#) on a piano.

The tuning system on ordinary keyboards is an artificial one, based on and adapted from the natural harmonic series. Around the time of J.S. Bach, equal temperament as a favored tuning system came into being to solve the problem of modulating through different keys. (Bach did not entirely welcome it. Its sound was inferior to the sweet concordances of just intonation). Equal temperament divides the keyboard octave into twelve equal parts, assigning a measurement of 1200 cents to the octave, with each half-step being 100 cents. Half-steps are of course fixed on the piano, but a violin could play a variety of c#s, anywhere from 50 cents to 99 cents away from the original C, and then 50 cents above the c#. These are defined as microtones, and are often considered harsh and out-of-tune to our Western ears, except for the wonderful 'bent' pitches found, for example, in Blues, Folk, and so on. Other cultures such as those of the Middle East, Asia and India have been creating music with microtonal scales for centuries.

Using Editor Librarian and Vision software on a Macintosh computer, the DNA tunings were programmed in as microtonal "scales" for each base:

Wave and Hertz Numbers			
Hz # and Note	Wave # (cm ⁻¹)	Hz # and Note	Wave # (cm ⁻¹)
Adenine		Thymine	
315.6 (D#)	723	322.1 (D#/E)	738
347.9 (F)	797	330.4 ((E)	757
368.0 (F#)	843	354.4 (F)	812
379.8 (F#/G)	870	363.2 (F#)	832
398.1 (G)	912	406.4 (G#)	931
408.1 (G#)	935	427.8 (G#)	980
447.4 (A)	1025	447.4 (A)	1025
490.2 (B)	1123	523.8 (C)	1200
504.2 (B)	1155	543.4 (C#)	1245
545.6 (C#)	1250	600.2 (D/D#)	1375
582.7 (D)	1335	733.3 (F#)	1680
598.0 (D/D#)	1370	768.2 (G)	1760
619.8 (D#)	1420	1248.3 (D#)	2880
632.9 (D#/E)	1450	1274.6 (D#/F)	2920
654.8 (E)	1500	1385.8 (F)	3175
698.4 (F)	1800		
726.7 (F/F#)	1665		
1139.2 (D)	2610		
1178.5 (D)	2700		
1248.3 (D#)	2880		
1278.9 (D#/E)	2930		
1366.2 (F)	3130		
1440.5 (F/(F#)	3300		
Guanine		Cytosine	
300.3 (D)	688	305.6 (D#)	700
305.6 (D#)	700	345.7 (F)	792
339.2 (E/F)	777	357.9 (F/F#)	820
370.2 (F#)	848	420.3 (G#)	963
383.2 (F#G)	878	429.1 (G#)	983
413.4 (G#)	947	440.9 (A)	1010
487.6 (B)	1117	504.2 (B)	1155
512.9 (B/C)	1175	537.8 (C/C#)	1232
529.5 (C)	1213	558.7 (C#)	1280
550.0 (C#)	1260	584.9 (D/D#)	1363
600.2 (D/D#)	1375	639.5 (D#/E)	1465
615.5 (D#)	1410	654.8 (E)	1500
641.7 (D#/E)	1470	713.7 (F/F#)	1635
663.5 (E)	1520	1276.8 (D#/E)	2925
728.9 (F/F#)	1670	1375.0 (F)	3150
1169.8 (D)	2680	1475.4 (F#)	3380
1278.9 (D#/E)	2930		
1366.2 (F)	3130		
1462.3 (F#)	3350		

2. Infrared tunings and musical scales.

[Figure #2] (Infrared tunings and musical scales.)

Story: The Art

Before describing what the tunings sounded like, it is of interest to address a rational for doing this at all. Pythagorus (6thC BC), who is credited with explaining musical harmonics to the Western world, is reputed to have described a stone as frozen music (1. Homage to Pythagoras). He knew nothing of physics but intuited that the mathematics of frequency which occur in processes such as planetary rotations, cycles of the seasons, right down to the atomic world of elemental matter, are not just lifeless pieces of data but reveal movements, rhythms, relationships and

other such as 254 and 257 Hz...two very slightly different middle Cs. The frequencies will be heard as the same pitch, C, but slightly out-of-phase. The phasing results in occasional louder moments, or “wa-wa” beats, when they do phase together. To the ear this bears a striking resemblance to the quality of ‘aliveness.’.....or organic movement found in any living process.

As these microtones were played over and over on the synthesizer, some arrestingly beautiful combinations began to appear, but, what to do with them?

Compositional Considerations

Microtones present formidable complications for composers, not to mention performers. First of all it is virtually impossible to play them on a normal keyboard. Microtonal scales can be mastered, with practice, by those performing on stringed instruments such as cellos and violins, who can play any pitch on their string, once they have found it. However, microtones are often too difficult for many ‘fixed pitched’ instruments such as clarinets and trumpets. The voice has the easiest time matching microtones. If a singer’s ear can hear it, s/he can produce it. And percussionists, of course, need not worry about them at all.

In addition to difficulty of tone production, microtones play havoc with the idea of ‘key,’ or tonality. What one is working with is a clump of ‘random’ sounds with no seeming tone order or organization at all. However, something very interesting began to happen. After weeks and weeks of experimenting with different sound combinations on the synthesizer, a tonal center began to emerge. One pitch seemed to draw other pitches to it...to lend coherency to the mass. This pitch turned out to be a kind of a C#, common to all the bases:

- Adenine: 545.6 Hz
- Guanine: 550
- Average Hz = 544.2
- Thymine: 543.4
- Cytosine: 537.8

Most pianos are tuned to around 554 for C#. An acute ear would be able to discriminate between 554 and 544....an approximate 1/4 tone. It is important to emphasize that this discovery was cemented musically in the compositions first by the ear, and not by the data. The above numbers were only discovered later. If one looks at the pitch chart (Fig. 2) one can see that this C# is found in all four bases almost exactly in the middle of each column. Also, it is positioned almost exactly in the center of the absorbency rates, and shows up as the average. This C# seems to act as a balancer for the entire spectrum of frequencies.

The pitch which shows up the most frequently and ought to have asserted itself as a tonic, or tonal center, is F#. It is found no less than three times in each base collection. But instead it is its fifth, the C#, which acts as the organizing force. The first composition, *Sequencia*, was written for tabla, or tuned drum, with the drum tuned to C#. The drum keeps a steady rhythm throughout the ensemble sections. While the synthesizer plays an ostinato, or repeating pattern, with the original sounds of the frequencies, the added instruments- violin, cello and voice – revolve harmonically around this central stabilizing force and match the tunings with their melodic shapings.

It is interesting to observe that most of the gongs, bells and drums of the non-Western world are tuned to this keynote, suggesting further that perhaps we, as a planet (not to mention as a body), may be trying to collectively tune to something. One theory involves a recently discovered pulsar called Vela X (PSR 0833) which collapsed into its pulsar state about 11,000 years ago. It is beaming radio waves towards earth with a period frequency of 11.24Hz, or an F# equivalent (2. Encyclopedia of Science & Technology). Its fifth, or C#, turns out to be a frequency of 16.86 or 539.52.....exceedingly close to our DNA 544. The emissions, scientists think, come from a combination of spin and strong magnetic fields. No one knows for sure if these emissions and their periodicities, which are regular, have an effect upon our energy fields.

Are The Frequencies in DNA Bases Harmonically Ordered?

They most certainly are. By comparing all 60 pitches one can find all of the precise ratios found in the first 16 harmonics of the overtone series: octaves, P5th, P4ths, Major and minor thirds, Major and minor 2nds and 7ths; even a 'flat' seventh. Mathematically, the odds of this happening at random are almost non-existent. This author has not taken the time to measure the higher harmonics, but Randy Masters of Aptos, California, is refining this step of the process (3. personal conversation). He is trying to discover a fundamental that could possibly be generating all of the DNA frequencies as overtones. This finding would be invaluable to all those involved in sound and the healing arts as well as scientists, and artists.

The compositions did not make particular, conscious use of the simpler, perfect ratios. But the ratios are there, doing their work, as are all the microtonal relationships. What is more important is the raw sound. Eikos, for instance, (only on the CD recording) pays extreme attention to the way the violin enters into, explores and leaves single synthesized tones. Its energy is zen-like; subterranean, with a playful middle section.

It is not known what information is encoded in these ratios, but one particular pattern appears striking. Figure #3 shows a curious leap in all four bases from the pitch F# up to the D# above, roughly a Major 6th/minor 7th. The interval in-between, G to D, contains no measurable frequencies at all. Its mirror, the G to D an octave below, contains a tightly packed cluster of 22 frequencies, over a third of the total frequencies measured.

What is the function of this 'shadow' gap? Is it just a coincidence, or are we looking into some kind of anti-matter, fourth dimension? More and more we are finding that things contain their complements; their opposites. It is almost a given 'law' of the universe. This 'gap' could be important, especially because both are balanced on their lower and upper edges by D#-F# intervals: nine pitches in the lower cluster and 10 pitches in the upper cluster. Almost perfect symmetry.

Possible Physiological Manifestations Through the DNA Code

*"The trick is to hear the music that is the body.
If we can do so, the meaning of the body can be transformed.
It becomes not a blind, silent, doomed machine
but a glorious composition,*





*a part of God's oeuvre... 'The Great Tone.'
Meaning and Medicine, Larry Dossey, M.D.*

Again, MATH makes processes visible. It decodes meanings. We can see the self-organizing power of the universe, and because the universe is a community it is constantly communicating. Are the sounds of DNA communicating anything to us?

Sequencia first begins to communicate through its concept, that we can hear the hidden beauty of life. This helps to give us a perspective – to find our place in the “Great Tone.” This comes directly out of the ancient Greek definition of education: the purpose of studying science and the natural world is to find our proper place in it, allowing us to fulfill our role in the larger pattern. It is truly “student-centered learning,” and the natural world is the primary educator. Art processes which translate directly from nature allow us deeper access into levels of being. And art is of course a celebration.

The second way Sequencia communicates is simply because it is music. This is more than a casual statement. We are attracted, often like moths to a flame, to music. One explanation is that composed music can be seen as a metaphor for life itself.

Music, or organized sound, is just about perfect as a metaphor for life. It is born, goes through a process of evolution and transformation, perhaps repeats itself or creates new avenues of life, and dies. (If you really listen, after it is over you can still hear the sounds continuing). The components of music express a yearning for balance. Energy is gathered together for forward motion, and then is released. Pulses, small ones for frequencies, larger ones for rhythms, and still larger ones for phrasing all act in concert. Relationships are constantly forming and re-forming as new tones, rhythms and events come into the picture and others recede.

Music is the active way we live our lives; the way we like our lives to be. It is the very life process itself. If the music doesn't flow we are deeply disturbed. How long can you tolerate a stuck recording? Bringing physics into the picture adds to this metaphor. Music (literally) mirrors the essence of nature itself in its chaos patterns and mathematics.

The same mathematical formula that characterizes the ebb and flow of music has been discovered to exist widely in nature: the flow of a river, beating of a human heart, the wobbling of the earth's axis. This is more than just simple pulse. The rhythms closely resemble irregular patterns of coastlines, clouds and mountain ranges, and other natural scenery. The brain must, then, on some level perceive its reality as a musical, complex landscape. And turning this around, the music we hear must feel like our earthly home. No wonder we love it.

It is likely that something unusual is being communicated directly through the combinations and ratios of spectral music. The descriptive adjectives one hears most often are: soothing, comfortable, a feeling of spaciousness, expansion.

Sequencia is not “new age” or demonstration music, nor was it composed it to “heal” anyone. It was written because that is what a composer does in the world; write music. But after ten years of hearing unique reactions and virtually no complaints from those who hear these strange tunings for the first time, one cannot help but wonder what is going on. Some listeners admit that they never (or hardly ever) listen to music because it ‘interferes with what is going on in their heads’ or is too invasive. However, they love, even crave, these DNA sounds. About one in every 4 or 5 persons has a deep, almost devotional response. Movement teachers love it, saying their students respond deeply. Would people react in the same way to compositions employing 60

random, microtonal combinations? Who knows? And certainly there are endless styles of tonal arrangement, given the same musical materials to begin with. But these particular DNA ratios, originating in light, are profoundly arresting to the ear. This first wakes up the nervous system, puts it on alert. What follows in sound is then allowed to enter our psyches on a deep level. People report feelings of connectedness, familiarity. "I feel right at home," they say. It is tempting to speculate that the body is recognizing itself, and is communicating this to the psyche.

The Impact of Sound Upon The Body

No one knows how sound, the raw stuff of creation, impacts our being; our consciousness. Mysteriously, we decode meanings which come to us through sonic carrier waves, perceiving these waves as a full-body experience not only through the ears but directly through the bones, tissue and matter of the body. The body mass feels sound as pressure. We know that the body is constantly piezoelectric, translating pressure into electrical signals, such as the way in which the inner ears send signals to the brain. Sound, therefore, impacts the many realms of the molecular world directly and somehow finds its way to the parts of us that make meanings.

We know for sure from the work of many medical institutions that sound can affect hormonal levels and other physiological systems of the body. Dr. Valerie Hunt of Malibu Beach, Ca. (4. Infinite Mind: The Science of Human Vibrations.), has done extensive work measuring the strengthening effects of sound upon the auric field, the energy field surrounding the body. Dr. Hunt did most of her research while a professor at UCLA. And there is no doubt that a sophisticated knowledge of resonance has led many practioners and researchers throughout the world to use sound in a variety of successful ways. Some introduce sound frequencies directly into the body with their voices, the client's voice, or by machine. Their methods can often create coherency, allowing the patient's natural healing ability to take over. This harmonious state can clear up chaos and static.

Communication on all levels, physiological and emotional, often becomes clearer and brighter; healthier. Nature loves these resonant states where very little energy is wasted.

There is every reason to believe that our psyches and physiologies can recognize the light, infrared patterns of life through the resonance of sound. What we do with that information is anyone's guess.

Conclusions

The story that presents itself as one works with the spectral tones of DNA is one of underlying beauty and order...an order suggesting freedom to express and improvise within the matrix. The fact that perfect harmonic ratios exist within its frequency data could, and should, lead to further stories of interconnectedness with the rest of life and the universe, since so much of our world is so ordered. We express creatively through harmonic proportions and their variations in our music, our architecture, paintings, dance – in virtually all that we are and do down to the design of a pack of cards, using the Golden Rectangle (whose sides have a phi relationship).

Certainly the freedom to express and improvise has been our salvation as a species for thousands of years. Our music has always reflected these two things: a love for order and spontaneity. DNA, the chemistry of life, seems naturally at home in a musical venue. For in our inner beings and in

our listening there has always been a deep yearning; a knowingness that music is who we are. The mystic Sufi poet Rumi said it best:



"All day and night, music. A quiet, bright reedsong. If it fades, we fade."
Quatrains, Rumi

Coda: Future Projects

Composition continues into the exploration of the genesis of musical forms from the physical properties of matter. The author is writing music for a multi-media project called Evolution 2000, using tuning banks from the frequencies of pulsars, from the magnetic spins of atomic nuclei (Larmor Frequencies) and other natural phenomena. Dr. David Deamer generously continues to advise and further the research.

Figure Legends:

Spectrophotometer readouts of wavenumbers of the four DNA bases: adenine, guanine, thymine and cytosine.

Frequencies (Hz) and wavenumbers programmed into the synthesizer for author's tuning system.

Placement of DNA frequencies for each base molecule arranged from 'low' to 'high' on a keyboard.

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The Music

Sequencia, (cassette and compact disc). Three original compositions by Susan Alexjander, using microtonal scales derived from the infrared spectra of adenine, guanine, thymine and cytosine. Performed by voice, tabla, violin, cello and synthesizer.

DNA Suite: by D.W. Deamer. (Cassette) keyboard realization of direct translations of nucleotide sequences in the human insulin gene; two satellite DNAs, and Alu Consensus, a 300 nucleotide repeating sequence that surprisingly comprises over a tenth of the human genome.

Molecular Meditation: by David Deamer. (Cassette) – synthesizer translations of nucleotide sequences in an antibody gene.

Produced by Science & The Arts:

Susan Alexjander, aka: Susan Alexander
Science & The Arts
PO Box 428
Aptos, Ca. 95001
831-421-0934
xjander@got.net

Dr. David Deamer
Department of Chemistry and Biochemistry
University of Ca. Santa Cruz
Santa Cruz, Ca. 95064
459-5158 (tel/fax)
deamer@hydrogen.ucsc.edu

BIOS:

Susan Alexjander holds a Masters degree from San Jose State University in Composition and Theory. She has taught at the university level and is currently an adjunct faculty member of Union Institute in Sacramento, California. Her compositions have been performed throughout the United States, including collaborations with dance companies. Sequencia is internationally known and has appeared on CNN, BBC Radio, Wisconsin Public Radio, and featured at the Boston Museum of Science, the San Francisco Museum of Modern Art and the Art Museum of Santa Barbara. In 1995 she received a Fellowship from the Alden B. Dow Creativity Center in Midland, Michigan, to explore the geometry of the mineral kingdom as musical data.

She is Director of Science & The Arts, a company founded by Dr. David Deamer, which furthers the research into the 'musical' universe of frequency. Her book, Sound Healing: A Guide To Therapeutic Practices, will be published by Crossing Press, Freedom, Ca. in Spring of 1999.

Dr. David W. Deamer is professor of Chemistry and Biochemistry at the University of California, Santa Cruz. His undergraduate B.Sc. degree was in Chemistry, at Duke University, Durham NC (1961) and his Ph.D. in Physiological Chemistry from the Ohio State University School of Medicine (1965). Following post-doctoral research with Profs. Lester Packer and Daniel Branton at UC Berkeley, he joined the faculty at UC Davis in 1967.

In 1994 he moved his laboratory and teaching appointment to UC Santa Cruz.

Dr. Deamer's NASA-supported research concerns the role of membranes in the evolutionary events leading up to the origin of cellular life. His laboratory has been continuously supported by the Exobiology program since 1985. Dr. Deamer's NIH-supported research is related to the discovery that single stranded RNA or DNA move through a bacterial toxin channel and can be characterized by the resulting blockades in ionic current.

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